

GAMMA RAY COSMOLOGY: THE EXTRA GALACTIC GAMMA SPECTRUM AND METHODS TO DETECT THE UNDERLYING SOURCE*

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ABSTRACT

We discuss the possible sources of extragalactic gamma rays and methods to distinguish the different sources. The sources considered are 1) Early Universe decays and annihilation of Particles, 2) ANG Sources and 3) Baryon-Antibaryon Annihilation in a Baryon Symmetric Cosmology. We describe the energy spectrum and possible angular fluctuations due to these sources.

I. INTRODUCTION - COSMOLOGICAL RADIATION

The study of the early universe proceeds largely by observing relics of an earlier period. The relics discovered or interpreted in this way, so far, are:

- i) Baryon Excess - GUT Era to SU(2)XU(1) Era
- ii) Relic Neutrinos (undetected) - 1 sec
- iii) Primordial Nucleosynthesis - ~ first 60 sec
- iv) 2.7° Microwave Radiation - ~ 300,000 years

Clearly detection of more relics of the early universe is urgently needed, if they exist, to gain a better understanding of the evolution and properties of the early universe.

Windows on the early universe are mostly obscured by dust or gas in the universe. There are two windows in the electromagnetic spectrum in which to obtain cosmological information ($Z > 10$ for example) before galaxy formation: 1) the microwave region and 2) the MeV Gamma Ray region. As discussed most recently by Spergel (1989) and previously by Stecker (1973), the universe is relatively transparent to a few MeV to GeV radiation (see Figure 1).

What cosmological information could we learn from this region of the spectrum? In the first place they could be unstable particles and the annihilation of relatively long lived particles such as cold dark matter particles. One example of a decay process is the decay of a few GeV gravitino (Olive and Silk; Stecker and Tylka, 1989)

$$\tilde{G} \rightarrow \gamma + \tilde{\gamma}$$

at $\sim 10^7$ sec. Figure 2 shows the type of structure that could be detected from such a process. Heavy long lived neutrinos could give similar effects (for example a 4th Family

neutrino with a mass of ~ 100 GeV and a lifetime of $\sim 10^7 \rightarrow 10^{10}$ sec)(D. Cline, Y.T. Gao, 1990).

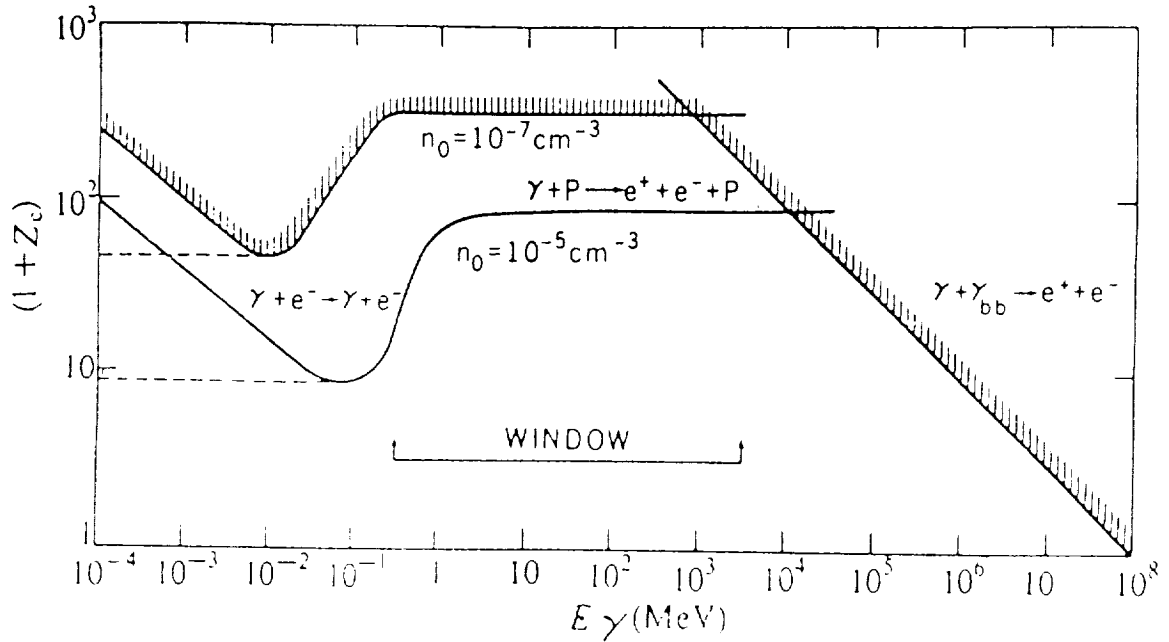
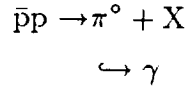


Figure 1. Redshift at which the universe becomes opaque to photons as a function of observed energy. n_0 is the mean atomic density of the cosmic medium.

Another cosmological effect could be the detection of significant gamma ray flux from



This could establish a significant component of antimatter in the universe (see, for example, Stecker 1973).

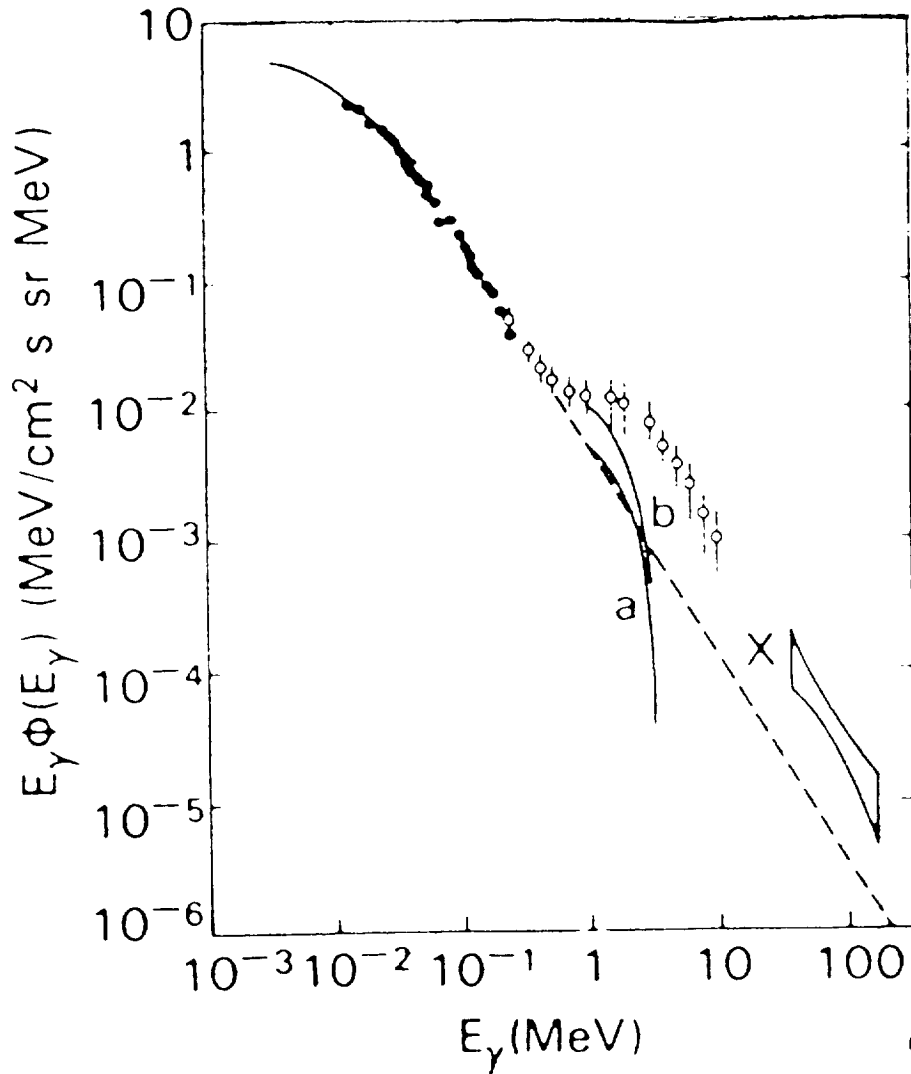
The most pressing question is how to extract signals for the cosmological effect. It is essential that first a diffuse, extragalactic component of the gamma ray spectrum be established. This has only been done for the energy range of 1 MeV – 20 MeV, so far. The rapidly falling spectrum and the poor gamma ray telescopes used, so far, have combined to make this a very difficult problem. GRO and EGRET will be of great significance in this regard.

Once a diffuse extragalactic signal is established, the search for cosmological components can be started. there are two techniques proposed so far

- i) Observation of structure in the energy spectrum that is related to the cosmological effect
- ii) Study of the angular distribution fluctuations compared to observe the underlying source (D. Cline and Y.T. Gao, 1989).

At present the activity is one of modeling the various extra galactic processes and cosmological processes to see if the magnitude of the expected effects are comparable to the

observed properties of the gamma ray spectrum. We call these effects Gamma Ray Cosmology. A related issue is the required characteristics of telescopes (Energy and angular resolution and viewing area) that can be used to observe these cosmological effects.



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Figure 2. The Observed CGB energy spectrum together with the critical spectra from: a) Stecker (1988) and b) Olive and Silk (1985).

In this report we describe a program that has been initiated at UCLA to identify the possible signals of γ Cosmology.

II. FINE SCALE ANISOTROPY TO IDENTIFY THE UNDERLYING SOURCE

Y. T. Gao and I have been studying the type of angular fluctuation that could come from various models of the diffuse, extra galactic gamma radiation (D. Cline and Y.T. Gao, 1989 and Gao, Cline and Stecker, 1990).

There are currently two attractive theories predicting a diffuse background which are the active galactic nuclei (AGN) model and the baryon-symmetric big-bang (BSBB) model.

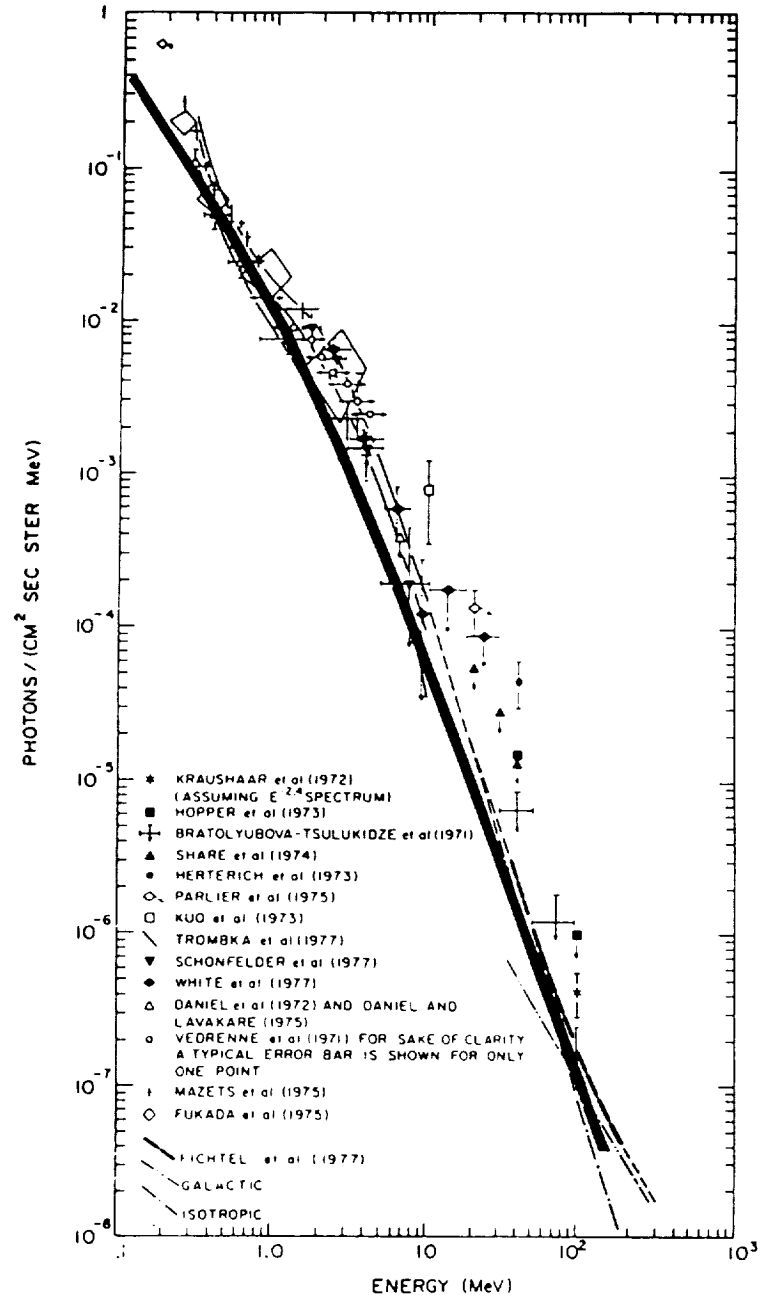


Figure 3. Energy spectrum of cosmic ray background (heavy line) calculated by Cline and Gao (1989)[for reference to the data see this paper as well].

We notice that the AGN and BSBB models give rise to different intensity fluctuation patterns and we need to investigate how the new-generation high-resolution telescopes can pinpoint the generation mechanisms.

Bignami, Fichtel, Hartman & Thompson (1979) have shown that both quasars and Seyfert galaxies could make a large contribution to the diffuse flux but there is still a great deal of uncertainty because of the very limited sample of active galaxies from which γ rays have been detected and because of the possibility of the evolutionary effects in these

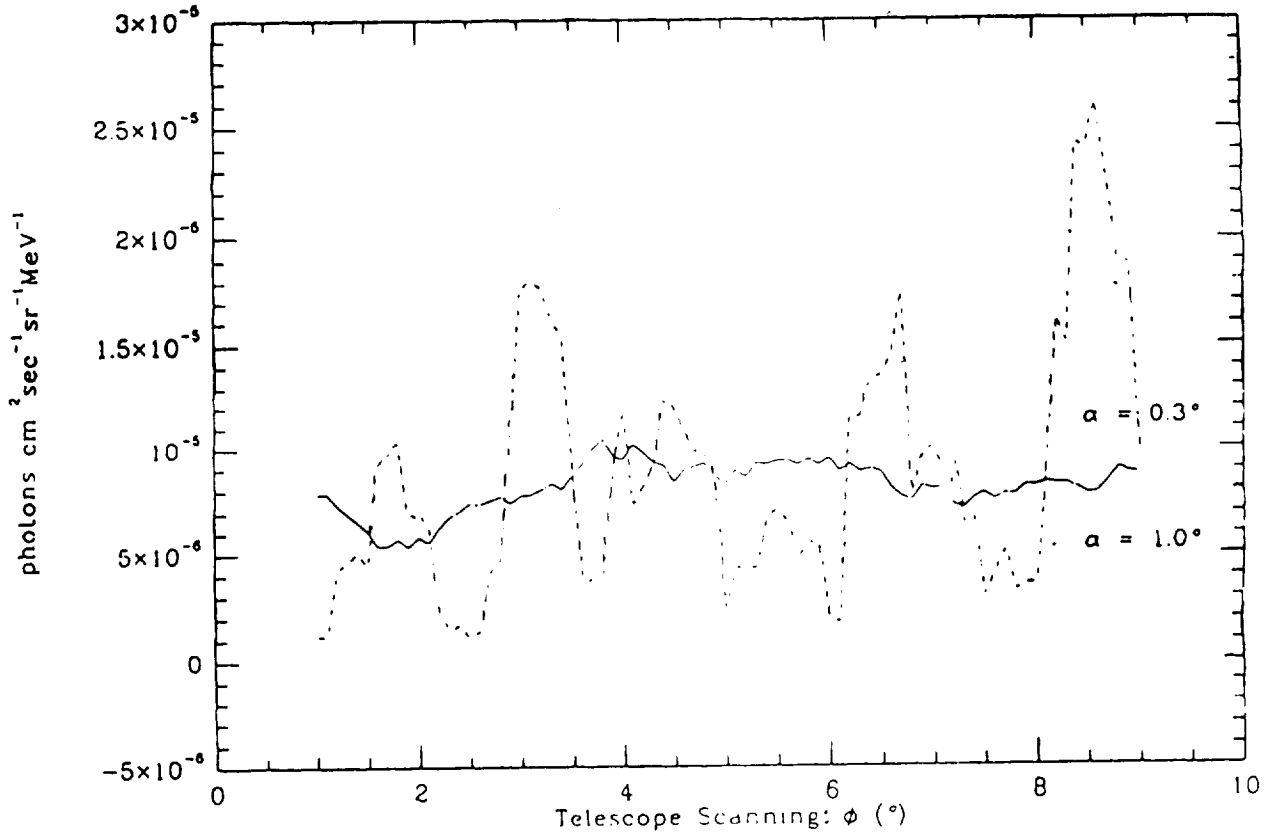


Figure 4.

galaxies at very large redshifts. Based on the pioneers' work, differential intensity of the background radiation is given as follows,

$$j(E_o, t_o) = \frac{dJ}{dE} = \frac{c}{4\pi H_o} \sum_i \int_{z_{min}}^{z_{max}} \frac{Q_i(E_o(1+z), z) n_i(z)}{(1+z)(1+2q_o z)^{1/2}} dz \quad (1)$$

(photons cm⁻²sec⁻¹sr⁻¹KeV⁻¹)

where q_o is the cosmological deceleration parameter; $n_i(z)$ is the comoving density of galaxies of type i ; $Q_i(E, z)$ is the average source strength or emissivity (photons per time interval and energy interval). That expression is valid for the standard universe in the matter dominated era and the absorption has been reasonably assumed negligible.

Assuming active galaxies (mainly quasars and Seyfert galaxies) dominated the γ ray background, we perform the Monte Carlo simulation with the AGN model we predict, with the new generation γ ray telescopes, the following effects might be observable:

1. As expected, the extragalactic γ ray background is largely reproducible with the contribution from AGN's only. However, simulation can not reproduce the observed MeV bump very well (Figure 3). This poor reproduction quality of the bump strengthens the conjecture that there is more than one generation process involved, such as BSBB and/or the gravitino decay
2. Fig. 4 shows that the fractional deviation increases monotonically with the observed energy, as predicted. This is a cosmological effect and the reason is that there are

more AGNs at higher redshifts and the contributions from those far away AGNs are redshifted down to the lower energy regions. As Fichtel (private communication) points out, in high energy regions the background might be observed anisotropic with the GRO satellite, another new generation telescope which may go up in the next year or so.

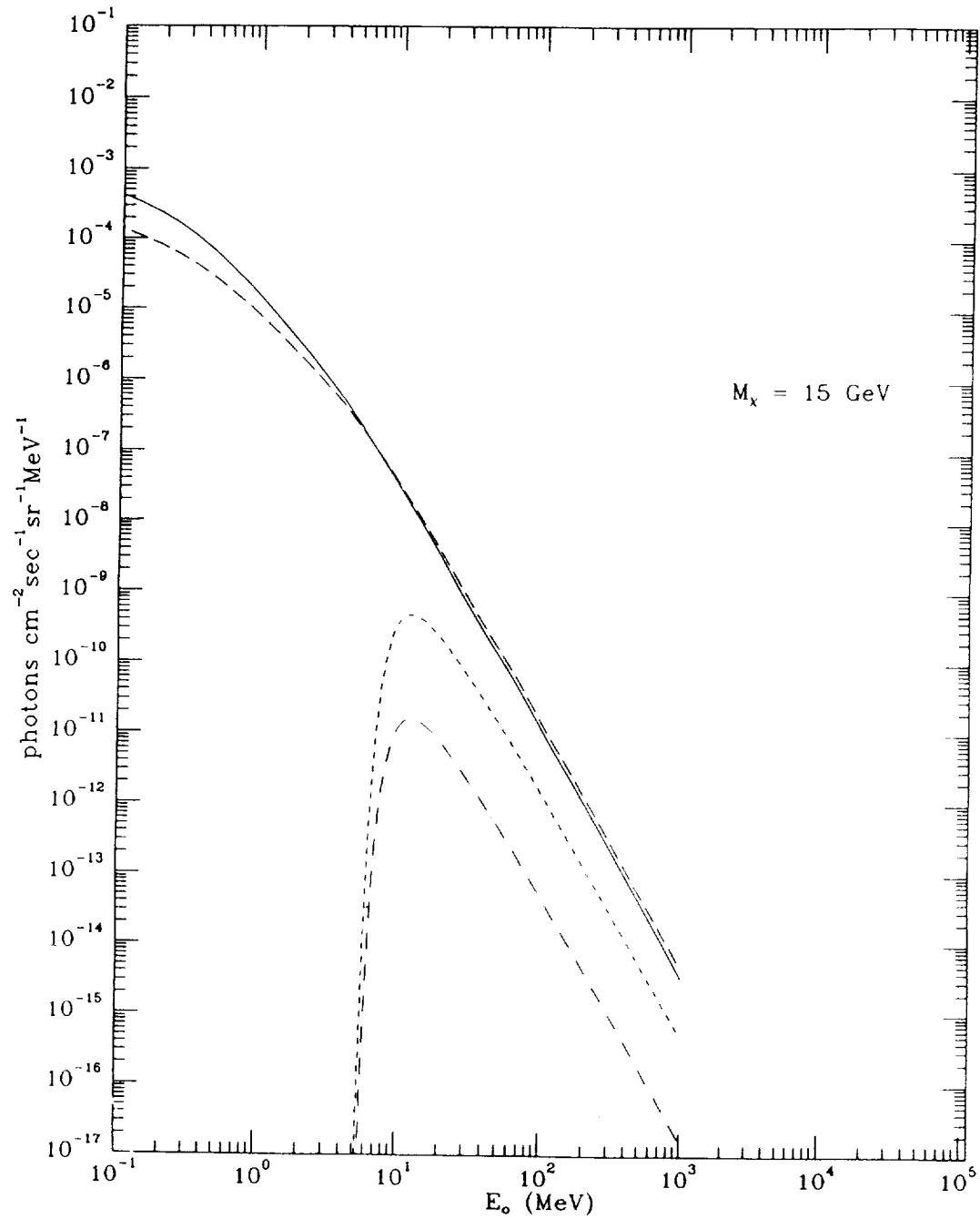


Figure 5.

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III. THE ANNIHILATION OF SUSY PARTICLES IN THE EARLY UNIVERSE

Part of the diffuse extragalactic spectrum could arise from the annihilation of exotic particles in the early universe. The remaining particles could form the Cold Dark Matter present in the Universe. We have carried out some simple calculation for photon lines and report some preliminary results here (see also, Stecker and Tylka 1989).

It would be of cosmological and particle physics importance if a characteristic feature of the low energy diffuse cosmic γ ray spectrum could arise from the annihilation of supersymmetric particles in the early universe. for example, for the annihilation occurring at $z \sim 10^3$, the energy of the present photons would be redshifted down to

$$E_{\gamma,0} \sim (z+1)^{-1} E_\chi \sim \text{MeV} \quad (2)$$

provided that $E_\chi \sim \text{GeV}$.

The essential feature of supersymmetric theories which makes them amenable to cosmological study is that, in many models, one of the superpartners are gauge fermions (gluinos, photinos, winos, etc.), Higgs fermions (higgsinos), scalar quarks and leptons (squarks and sleptons), and the gravitinos. In the very early universe, all these particles would be present in thermal equilibrium. As the temperature falls, the heavier ones decay into lighter ones. Eventually only the lightest supersymmetric particles (LSP) will be left. They can disappear only by pair annihilation.

By far the best candidates for the LSP are neutral gauge/Higgs fermions, which are in general mixed and the mass eigenstates "neutrolinos" contain both fermion and Higgs components. It is most probable that the LSP is either almost a pure higgsino \tilde{H} or a pure photino $\tilde{\gamma}$.

We take $H_0 = 65 \text{ kms}^{-1} \text{Mpc}^{-1}$, and use the simplification that χ , our specified type of LSP, is formed with either pure photinos or pure higgsinos. We also assume that the universe is χ -dominated, with $\Omega_{\text{tot}} = 1$. This assumption gives $\Omega_\chi \simeq 1$, implying that

$$n_\chi R^3 \simeq \text{const} \simeq n_{\chi,0} R_0^3 \quad \text{or} \quad n_\chi(z) \simeq \frac{\Omega_{\chi,0} \rho_{\text{crit},0}}{M_\chi} (1+z)^3 \quad (3)$$

where $n_\chi(z)$ is the cosmological number density of χ . In fact, the pair annihilation should be efficient enough to reduce the present day number density of the LSP to an acceptable level. Our assumption is nothing but an ideal case. Detailed discussions about $n_\chi(z)$ are in the literature.

CDM, including $\tilde{\gamma}$ and \tilde{H} , are non-relativistic at decoupling, i.e., $E_\chi \simeq M_\chi c^2$. The annihilation cross section is approximated by

$$\langle \sigma V \rangle_{\text{ann}} = a + b \cdot \frac{kT}{E_\chi} \quad (4)$$

where a and b are specific for particular models. Since $T \sim (1+z)$, we can, no loss of generality, consider two extreme cases, namely,

$$\langle \sigma V \rangle_{\text{ann}} = \langle \sigma V \rangle_{\text{ann}}^0 \cdot (1+z)^J \quad (5)$$

where $J = 0, 1$. The annihilation cross section today $\langle \sigma V \rangle_{\text{ann}}^{\circ}$ are taken as follows:

- $\chi\chi \rightarrow \gamma\gamma$:
 - $\chi = \tilde{\gamma}$: $\sim 8 \times 10^{-31} \text{cm}^3/\text{sec}$ for $M_{\tilde{\gamma}} = 5 \text{ GeV}$ and
 $\sim 6 \times 10^{-30} \text{cm}^3/\text{sec}$ for $M_{\tilde{\gamma}} = 15 \text{ GeV}$ (Rudaz 1989);
 - $\chi = \tilde{H}$: $\sim 2.5 \times 10^{-33} \text{cm}^3/\text{sec}$ for $M_{\tilde{H}} = 5 \text{ GeV}$ and
 $\sim 2 \times 10^{-31} \text{cm}^3/\text{sec}$ for $M_{\tilde{H}} = 15 \text{ GeV}$ (Rudaz 1989);
- $\chi\chi \rightarrow \text{hadronic jets} \rightarrow \gamma \text{ rays}$:
 - $\chi = \tilde{\gamma}$: The value $\sim 2.2 \times 10^{-27} \text{cm}^3/\text{sec}$, the
 maximum corresponding to the lower limit on the
 squark mass ($\sim 80 \text{ GeV}$)

Figure 5 show the results of these calculations. The expected flux is far too small to be separated from the observed diffuse spectrum.

IV. ANGULAR EFFECTS DUE TO A BARYON-ANTIBARYON SYMMETRIC COSMOLOGY

We have been carrying out calculations of the expected angular fluctuations in the diffuse gamma spectrum due to $\bar{B}B$ annihilation. Preliminary results (reported to the meeting) show that measurable and quite specific patterns of fluctuations may appear. This work is still in progress and will be reported elsewhere.

V. DETECTOR RESOLUTION AND VIEWING AREA REQUIRED TO DETECT THE UNDERLYING PROCESS

We held a workshop at UCLA in 1988 to determine the processes in the development of high resolution gamma ray telescopes (D. Cline and E. Fenyves, 1989). We believe that angular resolution on the milliradiation level and energy resolution of the less than 1% level are possible to achieve with new telescopes provided a strong R & D program is undertaken. Recently the UCLA/UT-D group has developed a scintillating fiber prototype that gives several m-rad resolution in the MeV energy range.

In order to detect the effects described here the viewing areas of the telescope need to be in the m^2 range and the time duration of years is likely required.

VI. SUMMARY

We have described work in progress at UCLA to estimate the magnitude of possible cosmological effects in the diffuse gamma ray spectrum and experimental techniques to observe these effects. The EGRET/GRO observations will be a key ingredient in the understanding of this possibility, hopefully leading to another generation of γ ray telescopes that are optimized for the search.

VII. ACKNOWLEDGEMENTS

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DISCUSSION

R.J. Slobdrian:

In this picture of baryon-antibaryon symmetry by what mechanism would one arrive at separated regions of baryonic and antibaryonic matter?

Floyd Stecker:

Such a universe could arise from a grand unified theory with spontaneous CP symmetry breaking. (see Stecker, F.W., 1985, Nucl. Phys. B252, 25, and references therein.)

